ANNUAL SUMMARIES

Atlantic Hurricane Season of 1993

RICHARD J. PASCH AND EDWARD N. RAPPAPORT

National Hurricane Center, NWS, NOAA, Coral Gables, Florida

(Manuscript received 2 June 1994, in final form 23 September 1994)

ABSTRACT

The 1993 hurricane season is summarized, and individual tropical storms and hurricanes are described. Overall, the season was relatively inactive, but tropical storms and hurricanes were responsible for a large number of deaths in South America, Central America, and Mexico. Only one hurricane, Emily, made landfall in the United States.

1. Introduction

For the third year in a row, there were fewer hurricanes and tropical storms than normal in the Atlantic basin during 1993. There were eight tropical storms, and four of these became hurricanes. These totals are below the most recent 50-yr averages of near 10 and 6, respectively. Emily, the season's only major and only long-lived hurricane, hit the North Carolina Outer Banks, causing serious damage over a limited area. In spite of the relative inactivity, tropical cyclones caused 280 deaths this year, largely as a result of disastrous mud slides in Venezuela during the passage of Tropical Storm Bret.

Tropical storm and hurricane tracks for 1993 are displayed in Fig. 1. No tropical cyclone reached hurricane intensity south of 21°N, continuing the absence of hurricanes over the deep Tropics observed in 1991 and 1992. Moreover, 1993 was the fourth consecutive year that no hurricanes were observed over the Caribbean Sea. Table 1 contains other statistics of the season. The season ended unusually early; the last named storm (Harvey) lost its tropical characteristics on 21 September. This is the earliest conclusion to tropical storms and hurricanes in a season since 1930.

The vertical shear of the horizontal wind is an important controlling mechanism for tropical cyclone development and intensification (e.g., Gray 1967). Figure 2 shows the anomalies, from the 1975–93 mean, of the magnitude of the vertical shear for the months of August and September 1993. All but one of the season's eight named storms formed in those months. Here the vertical shear is defined as the upper-tropospheric (approximately 200-mb level) minus the lower-tropospheric (approximately 900-mb level) wind. Also plotted in Fig. 2 are dots showing the locations of formation (where tropical depressions developed) of the tropical storms and hurricanes during August and September 1993. With one exception (Emily), the tropical cyclones developed in areas where the shear was indicated on this chart to be near normal or weaker than normal.

It is revealing to note the tracks of the individual tropical storms and hurricanes (from Fig. 1) with respect to the shear field shown in Fig. 2. Tropical Storms Bret and Cindy, along with Hurricane Gert, moved over areas of generally weaker than normal shear, but their strengthening was apparently limited by a close proximity to land (although Gert did intensify to category 2 hurricane status). Tropical Storm Dennis moved over open waters but into an area of stronger than normal shear, and it weakened to dissipation. Floyd and Harvey were at rather high latitudes but, as Fig. 2 shows, these two systems did move through areas of weaker than normal shear and both became hurricanes (although Harvey was a hurricane only very briefly). Probably the most interesting case was Emily. In the early stage of development, Emily was over an area of stronger than normal shear and remained a tropical depression for a couple of days. However, Emily's motion eventually carried it into the region of weaker than normal shear off the southeast U.S. coast, and the cyclone intensified markedly, becoming a major hurricane.

As noted above, the 1993 Atlantic hurricane season ended much earlier than usual. This was probably related to the premature reversal of upper-tropospheric

Corresponding author address: Dr. Richard J. Pasch, National Hurricane Center, 1320 South Dixie Highway, Coral Gables, FL 33146.

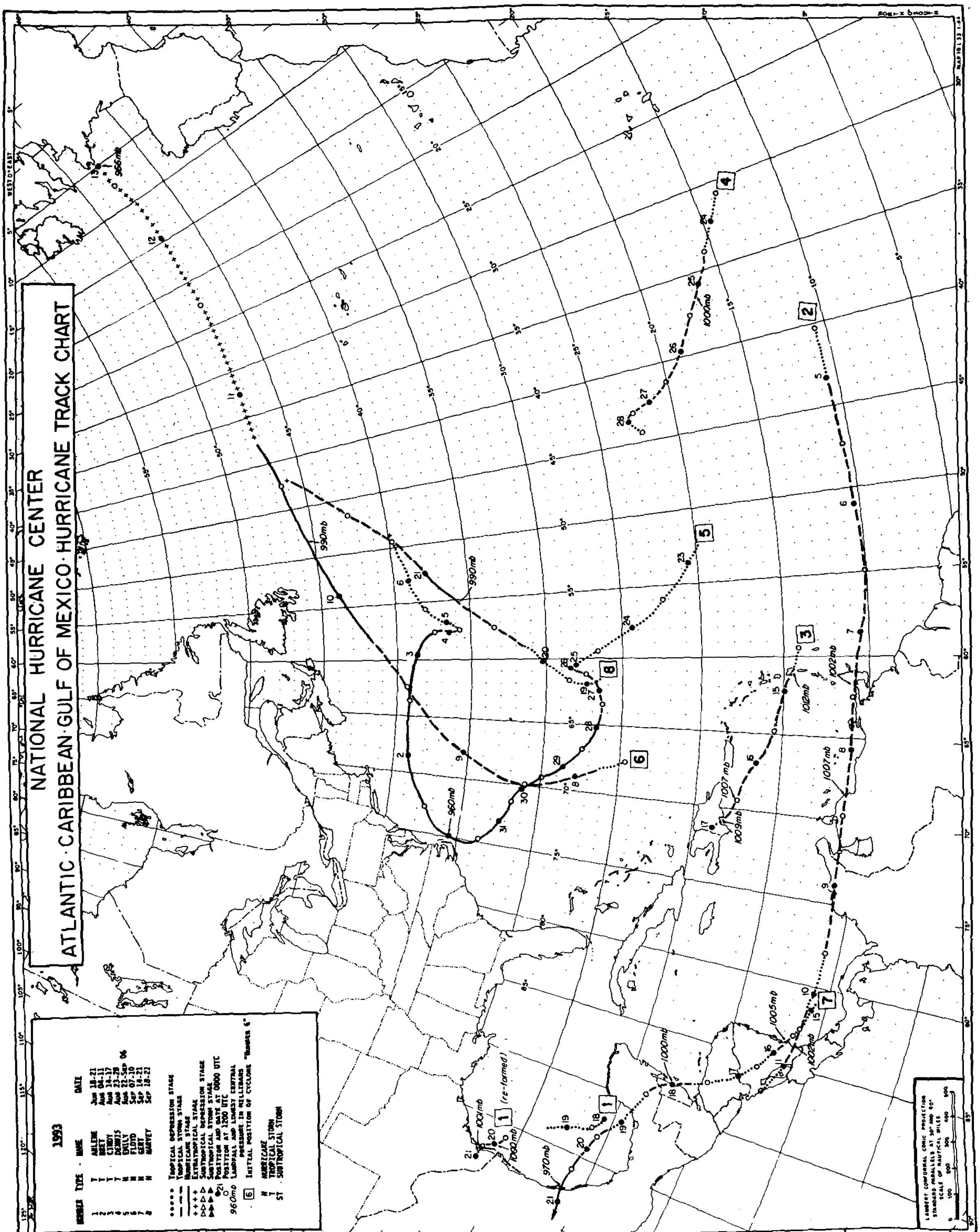

FIG. 1. Tropical storm and hurricane tracks for 1993.

flow, from easterly to westerly, over the eastern tropical Atlantic in the latter part of September 1993 (Avila and Pasch 1995). The increase in vertical shear over the tropical Atlantic (implied by this wind reversal) inhibited tropical cyclogenesis.

2. Individual tropical storms and hurricanes of 1993

a. *Tropical Storm Arlene, 18–21 June*

1) SYNOPTIC HISTORY

The year's first tropical storm, Arlene, formed from a disturbance that was noted on 9 June over the western Caribbean Sea and Central America. Satellite pictures over the following week indicated that the activity spread slowly northwestward and increased a little in areal coverage. During that period, upper-level winds over the northwestern Caribbean Sea and the Gulf of Mexico were generally from the west or northwest. This created a vertical wind shear that was not favorable for the development of a tropical cyclone. Nevertheless, the system persisted as a rainstorm that reportedly caused a landslide in El Salvador that killed 20 people.

On 16 June, a mid- to upper-level low began to develop over the Bay of Campeche. Over the adjacent Yucatán peninsula and the northwest Caribbean Sea, the flow aloft became more anticyclonic. In addition, on that date, a tropical wave neared the Yucatán peninsula from the east-southeast. The net effect of these changes was for the convective activity to expand west-northwestward into an area where the upper-level circulation was more conducive to the development of a tropical depression. Analysis of surface data suggests that by late on 16 June a 1008-mb low formed over the Yucatán peninsula.

A reconnaissance plane from the U.S. Air Force Reserves found only a broad area of low pressure in that area at midday on 17 June. However, satellite pictures a few hours later showed convective bands developing just offshore over the south-central Gulf of Mexico, and it is estimated that at 0000 UTC 18 June the system became Tropical Depression Two. The depression was centered between the low aloft to the southwest and a deep-layer-mean high to the northeast. The associated steering flow moved the depression toward the northwest at 2–3 m s^{-1}.

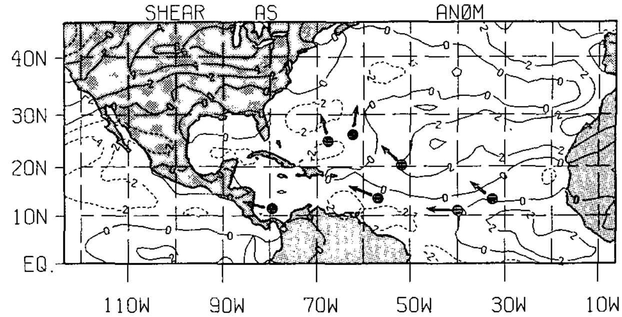

FIG. 2. Anomalies, from the 1975–93 mean, of the magnitude of the vertical shear of the horizontal wind (approximately 900 mb minus 200 mb) for August and September of 1993. Contour interval is 2 m s^{-1} with dashed contours for negative anomalies (i.e., weaker than normal shear). Dots show the location where 1993 tropical storms or hurricanes formed (became tropical depressions) in those two months, and arrowheads show direction of motion of the systems during early stages of development.

The center of the depression remained near the eastern edge of the low aloft, in an area of moderate southwesterly vertical wind shear that apparently precluded strengthening of the depression. The low-level center stayed diffuse, with satellite images occasionally showing separate weak low-level cloud swirls in that area. Indeed, the reconnaissance mission late on 18 June found 1006 mb to be the lowest pressure within a broad area for which the onboard meteorologists could not make a center "fix." By that time, satellite pictures suggest that the upper-level shear over the diffuse center had been further increased by a southwesterly outflow jet cutting across the southwestern Gulf of Mexico from eastern North Pacific Tropical Storm Beatriz.

In the meantime, on 18 June, deep convection became more concentrated in a band located 275–375 km mainly to the east of the center. Over the next 24 h, the

TABLE 1. 1993 Atlantic hurricane season statistics.

Number	Name	Class*	Dates**	Maximum 1-min wind (m s^{-1})	Minimum sea level pressure (mb)	U.S. damage ($ millions)	Direct deaths
1	Arlene	T	18–21 Jun	18	1000	22	6
2	Bret	T	4–11 Aug	26	1002		184
3	Cindy	T	14–17 Aug	21	1007		4
4	Dennis	T	23–28 Aug	23	1000		
5	Emily	H	22 Aug–6 Sep	51	960	35	3
6	Floyd	H	7–10 Sep	33	990		
7	Gert	H	14–21 Sep	44	970		76
8	Harvey	H	18–21 Sep	33	990		

* T: tropical storm, wind speed 17–32 m s^{-1} (34–63 kt). H: hurricane, wind speed 33 m s^{-1} (64 kt) or higher.
** Dates begin at 0000 UTC and include tropical depression stage.

band wrapped cyclonically around the center so that by early on 19 June a comma-shaped band of thunderstorms extended from well northwest through north through southeast of the center. Satellite pictures and reconnaissance data indicate that the center of a new and dominant (1000 mb) convective system, designated Tropical Storm Arlene, formed in the northwest part of the band around 1200 UTC on 19 June.

The new center initially moved northwestward at 2–3 m s^{-1} but then nearly stalled when an eastward-moving short-wave trough passed by to the north. The forward motion then became a westward drift. Arlene made landfall over Padre Island, about 75 km south of Corpus Christi, near 0900 UTC on 20 June and weakened to depression strength shortly thereafter. The system remained a tropical depression through 0600 UTC on 21 June. A low- to midlevel remnant circulation was detected for another day or two over the lower Rio Grande valley of southern Texas and northeastern Mexico.

2) Meteorological statistics

Although maximum sustained wind speeds near Arlene's center are estimated to have been about 18 m s^{-1} for the 18 h ending at landfall, somewhat stronger winds were located well to the east of the circulation center, in the convective band. Sustained wind speeds of 21–23 m s^{-1} were reported between 1100 and 2000 UTC by ship *C6JP2* (name unknown) and several platforms over the north-central Gulf of Mexico (see Table 2a). Similar wind speeds in that vicinity had been encountered by the reconnaissance aircraft at a flight level of about 450 m. The distant wind maximum and the association of the tropical cyclone with the nearby low aloft indicate that Arlene's structure had some subtropical cyclone characteristics.

Reconnaissance aircraft observed a central pressure of 1000 mb on seven consecutive penetrations of Arlene. This is the estimated minimum pressure of the storm. The pressure at landfall is estimated at 1001 mb.

Arlene generated storm tides of locally up to about 1.2 m along the Texas coast. The storm tide breached sections of Padre Island and caused local flooding on the mainland.

Heavy rain fell for several days over Central America from the weather system that eventually became Arlene. Heavy rains also occurred over Mexico (Table 2b). Arlene brought large accumulations of rain and local floods to the area extending inland about 275 km from the Texas coast. Locally heavy rain, from a combination of Arlene and a frontal system, also occurred in northeast Texas, Louisiana, and Arkansas. The town of Henderson, Texas, reported the largest total, 326.4 mm.

No reports of tornadoes associated with Arlene have been received by the National Hurricane Center (NHC).

3) Casualty and damage statistics

In Mexico, floods from Arlene killed five people (four in the state of Yucatán and one in the state of Campeche.) There was one flood-related fatality reported in Henderson. Damage in Campeche was reported at $33 million. Flooding from rainfall was also reported in Texas, Louisiana, and Arkansas. The Texas Division of Emergency Management estimated $22 million damage to homes, businesses, and infrastructure in that state. Crop losses were not quantified.

The storm tide (Table 2a) removed about 0.2–0.3 m of sand from some beaches along the lower Texas coast. Extensive tidal flooding was reported on the lower and middle Texas coast as well as along beach access roads. Beach erosion was also reported in southwestern Louisiana.

4) Warnings

Arlene was still a tropical depression when its center moved close enough to the coastline that the issuance of a tropical storm watch was considered by the NHC. However, because the cyclone was then quite poorly organized and significant strengthening was not forecast, the NHC, in coordination with the appropriate National Weather Service (NWS) offices, opted to delay issuing a tropical storm watch. When the new and slightly stronger center formed, a tropical storm warning was issued for Brownsville to Matagorda, Texas, about 21 h prior to landfall. There were no observations of sustained tropical storm force winds received from the warned area.

b. Tropical Storm Bret, 4–11 August

1) Synoptic history

Bret was spawned by a tropical wave that moved off the west coast of Africa on 1 August. This wave was among several, during late July and early August of 1993, that looked impressive in terms of amount and organization of deep convection. A few days later, the thunderstorm activity associated with the wave became more concentrated, and the development of curved convective bands was noted. Based on intensity estimates using satellite images (Dvorak 1984), a tropical depression is estimated to have formed from this system, about 1850 km to the west-southwest of the Cape Verde Islands on 4 August near 1200 UTC.

The cyclone moved on a westward course at an increasing forward speed during the ensuing 12–24 h. Around 0000 UTC 5 August, satellite intensity estimates indicate that the system strengthened to become Tropical Storm Bret. By 1200 UTC 5 August, Bret was moving westward near 10 m s^{-1}. This motion was maintained for the next 4 days or so, due to a strong deep-layer ridge that remained established to the north of the storm throughout most of its lifetime.

TABLE 2a. Tropical Storm Arlene selected surface observations, June 1993.

Location	Minimum sea level pressure: Pressure (mb)	Minimum sea level pressure: Date/time (UTC)	Maximum surface wind speed (m s^{-1}): Sustained wind	Peak gust	Date/time (UTC)[a]	Storm surge[b] (m)	Storm tide[b] (m)	Rain (storm total) (mm)
Texas[c]								
Brownsville WSO (BRO)	1004.0	19/2315	11	14	21/1021			80.8
Corpus Christi WSO (CRP)	1003.7	20/1116	11	16	20/0821			233.9
Navy Kingsville (NQI)	1002.1	20/1300	13		20/2000			105.1
Navy Corpus Christi (NGP)	1003.5	20/1056	12	15	20/1256			158.0
Palacios (PSX)	1008.1	19/2352	10	16	19/1851		1.2–1.5[d]	110.5
Victoria Arpt. (VCT)	1008.8	20/0852	9	14	19/2053			108.2
Port Lavaca							1.2	145.5
Port O'Connor							1.2	
Indianola							1.2	
Kingfisher Marina							1.2	
Bob Hall Pier						0.5	0.8	
South end South Padre Island						0.5	0.7	
Ship reports[e]								
C6JP2 (27.1°N, 92.8°W)			23		19/1800			
Commercial platforms[e,f]								
5R0 (28.2°N, 93.8°W, 37 m)			23	28	19/1348			
7W2 (28.5°N, 92.5°W, 29 m)			23	26	19/1103			
7R8 (28.3°N, 92.0°W, 31 m)			21		19/2000			
S58 (28.2°N, 90.7°W, 37 m)			21	23	19/1139			
01T (28.1°N, 94.4°W, 34 m)			21[d]	23	19/1946			
NDBC instruments[g]								
Buoy								
42002 (25.9°N, 93.6°W)	1006.3	19/1000	18	23	19/2000			
42020 (27.0°N, 96.5°W)	1005.1	19/1300	14	17	19/1300			
42035 (29.2°N, 94.4°W)	1009.7	20/1000	15	19	18/1700			
C-MAN								
PTAT2 (27.8°N, 97.0°W)			15	19	19/1633			
SRST2 (29.6°N, 94.0°W)	1011.3	20/0000	15	17	20/0000			

[a] Time of 1-min wind speed unless only gust is given.
[b] *Storm surge* is water height above normal tide level. *Storm tide* is water height relative to National Geodetic Vertical Datum, which is defined as mean sea level in 1929.
[c] One-minute-averaged wind.
[d] Estimated.
[e] Unknown averaging period.
[f] A more extreme value may have occurred.
[g] NOAA buoys report hourly an 8-min-average wind. C-MAN station reports are 2-min-average winds at the top of the hour and 10-min averages at other times. More extreme values may have occurred. Contact National Data Buoy Center for additional details.

The storm initially appeared to have adequate upper-tropospheric outflow for strengthening, and Bret's maximum winds increased to around 25 m s^{-1} by 0600 UTC 6 August. However, by 1800 UTC 6 August, the center of the storm became exposed near the north-northwestern edge of the main convective cloud mass. The dense overcast became reestablished over the center of the storm a few hours later, as Bret neared the island of Trinidad and the northern coast of Venezuela. Based on U.S. Air Force Reserve reconnaissance aircraft observations, the central pressure fell to 1002 mb just after 1800 UTC 6 August. The storm skirted the northern coast of Trinidad early (around 0800 UTC) on 7 August, and the center moved along a portion of the northern coast of Venezuela a few hours later. Figure 3 is a visible satellite picture of Bret over northern Venezuela. Around 2000 UTC 7 August, the center was back out over the water, just offshore of the coast, and by 0800 UTC 8 August, Bret moved over the extreme northwestern part of Venezuela. The center continued westward over the extreme northern sections of Colombia on 9 August.

After interacting with some mountainous terrain over Venezuela, Bret encountered a tremendously high mountain over Colombia, Pico Cristobal Colon, whose peak is about 5800 m above sea level. The circulation was weakened considerably by this mountain and Bret was reduced to a tropical depression when it emerged

TABLE 2b. Selected rainfall accumulations (mm) associated with Arlene and, over northeast Texas, Louisiana, and Arkansas, a combination of Arlene and a frontal system; E indicates estimate.

Location	Total
Mexico (18–20 June; some totals incomplete)	
Merida, Yucatán	E347.5
Panuco, Veracruz	200.4
Camargo SJ. 11, Tampico	185.9
San Jose Tecoh, Yucatán	6.94
P. Marte Gomez, Tamps.	6.56
Teocelo, Veracruz	5.55
Huajusco, Veracruz	5.30
Briones, Veracruz	5.12
Chetumal, Quinta Roo	5.02
Texas	
Henderson	376.4
Carthage	347.7
Longview	338.8
Brazoria	294.6
Marshall	292.9
San Manuel	290.6
Robstown	285.8
Jacksonville	285.2
Chalk Hill	279.4
Corpus Christi	267.5
Anahuac	250.7
Centerville	228.6
Hallsville	226.3
Tatum	208.0
Woodlawn	205.7
Armstrong	204.5
Palastine	202.2
Raymondville	201.9
Longville	198.4
Goliad	192.8
College Station	191.8
Kirbyville	190.0
Monte Alto	186.7
Alief	186.4
De Quincy	185.9
Bay City	183.1
McCook	182.6
Papalote	180.3
Angleton	174.8
Columbus	170.7
Banquette	168.4
Mission	168.1
Jewett	166.9
Jaspar	164.8
Falfurrias	164.6
Dime Box	164.3
Gladewater	160.5
Deweyville	160.0
BPT	159.0
Rincon	159.0
Engleman Gardens	158.5
Midway	156.7
San Jacinto Dam	156.2
Cypress	156.0
Concord	155.4
Portland	154.9
Washington State Park	154.7
Sour Lake	154.7
Sabine Pass	153.2
Overton	152.1
Nursery	151.4
Bishop	150.9
Calallen	150.6
Taft	149.6
Humble	148.3
Refugio	145.8
Wortham	145.0
Edroy	144.8
Easterly	144.5
Post Oak	144.0
Kountze	143.3
Orange	142.0
Conroe	140.5
Houston airport	140.5
Nacadoches	140.4
Alto	138.7
Agua Dulce	137.7
Somerville	137.4
Berclair	136.4
Cold Spring	135.4
Hebronville	135.1
Adams Gardens	133.6
Chapman Ranch	132.1
Whitehouse	132.1
Beaumont (city)	130.8
Bryan XIX NE	130.6
Weslaco	130.6
Eastham	130.3
Tyler	128.5
New Caney	128.5
Crockett	127.8
Weiss Bluff	127.8
Realitos	127.3
Louisiana	
Lake Charles	305.1
Shreveport	291.1
Jennings	191.5
Abbeville	180.3
Harleton	175.8
Keithville	164.1
Jefferson	159.8
De Ridder (5N)	148.3
Old Town Bay	147.3
Mooringsport	144.8
Oil City	137.2
Karnack	131.8
Arkansas	
Lewisville	127.5

over the waters of the southwest Caribbean Sea around 0900 UTC 9 August. Indeed, Bret was so severely disrupted by the mountains that the circulation had practically dissipated. However, later during the day on 9 August, convection increased in bands over the southwest Caribbean. The upper-tropospheric flow over the area was mostly straight southwesterly at the time Bret moved off the coast of Colombia, but later on 9 August

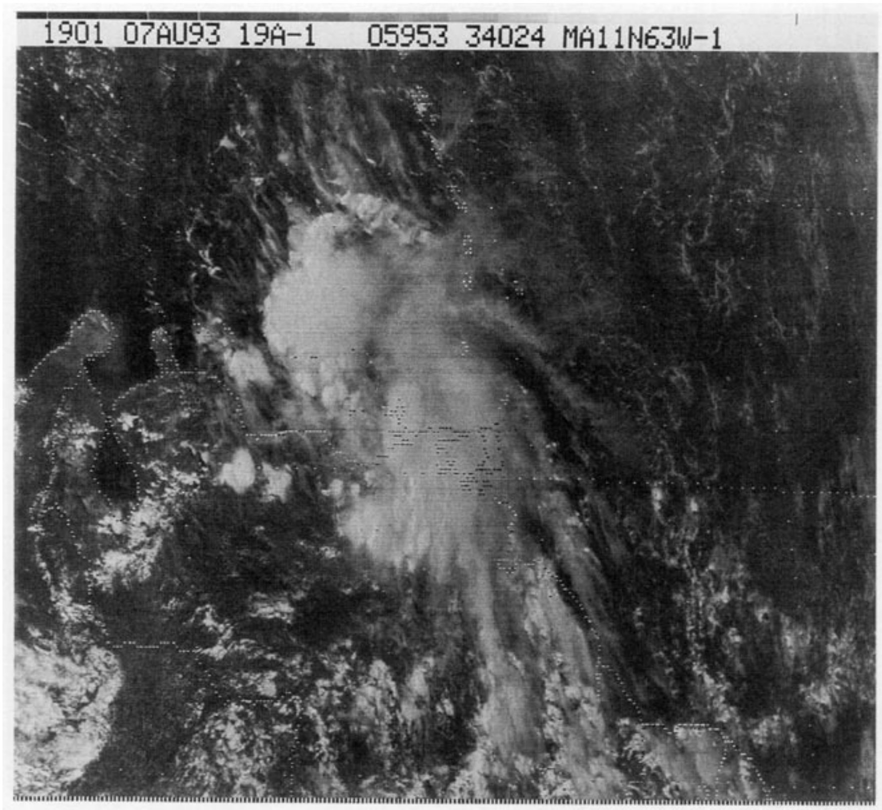

FIG. 3. *GOES-7* visible satellite image of Tropical Storm Bret at 1901 UTC 7 August 1993, as heavy rains began spreading over Venezuela.

the upper-level flow became increasingly anticyclonic. Bret regenerated into a tropical storm by 0600 UTC 10 August, while it was located about 260 km to the east of the southern coast of Nicaragua. The forward motion slowed to 5–7 m s^{-1} as the storm neared southern Nicaragua. Based on satellite intensity estimates, Bret's maximum winds were near 21 m s^{-1} when the center crossed the coast of southern Nicaragua near Bahia Punta Gorda around 1700 UTC 10 August. Figure 4 is a visible satellite picture of Bret just prior to landfall in Nicaragua.

After moving inland, Bret turned toward the west-northwest. It is considered to have dissipated as a tropical cyclone when it neared the Pacific coast of Nicaragua around 1800 UTC 11 August, because a low-level circulation could no longer be identified at that point. Nonetheless, a remnant disturbance could be tracked westward and then west-northwestward over the eastern Pacific for a few days. The system eventually regenerated into eastern North Pacific Tropical Depression Eight-E, which later became Hurricane Greg.

2) Meteorological statistics

The island of Margarita reported wind gusts to 24 m s^{-1}. The weather station on Grenada reported maximum sustained winds of 16 m s^{-1} with gusts to 20 m s^{-1}. A sailing yacht, the *Lady Elaine,* anchored at Hog Island on the south coast of Grenada, measured a sustained wind of 21 m s^{-1}. Guiara, Venezuela (near the first landfall point in South America), reported a wind gust to 20 m s^{-1}. The highest gusts reported from the islands of Curacao and Bonaire were 21 m s^{-1}. A ship, the *Probo Baro,* reported 20 m s^{-1} sustained winds just off the coast of Venezuela.

During the passage of Bret over Venezuela on 7–8 August, 339 mm of rain reportedly fell in a 10-h period at Guanare (state of Portuguesa). Another 24-h rainfall amount of 285 mm was reported from Quebarada Seca (state of Barinas). Among various reporting sites in Caracas, a maximum 24-h total of 152 mm was noted, with up to 120 mm occurring during a 7-h period.

3) Casualty and damage statistics

Flooding and mud slides, due to heavy rainfall associated with Bret, caused a major catastrophe in Venezuela. The government of Venezuela reported a total of 173 deaths and "many" missing. The majority of the deaths occurred in the low-income areas surrounding Caracas, where many people reside in ramshackle huts. Press reports indicated at least 10 000 were home-

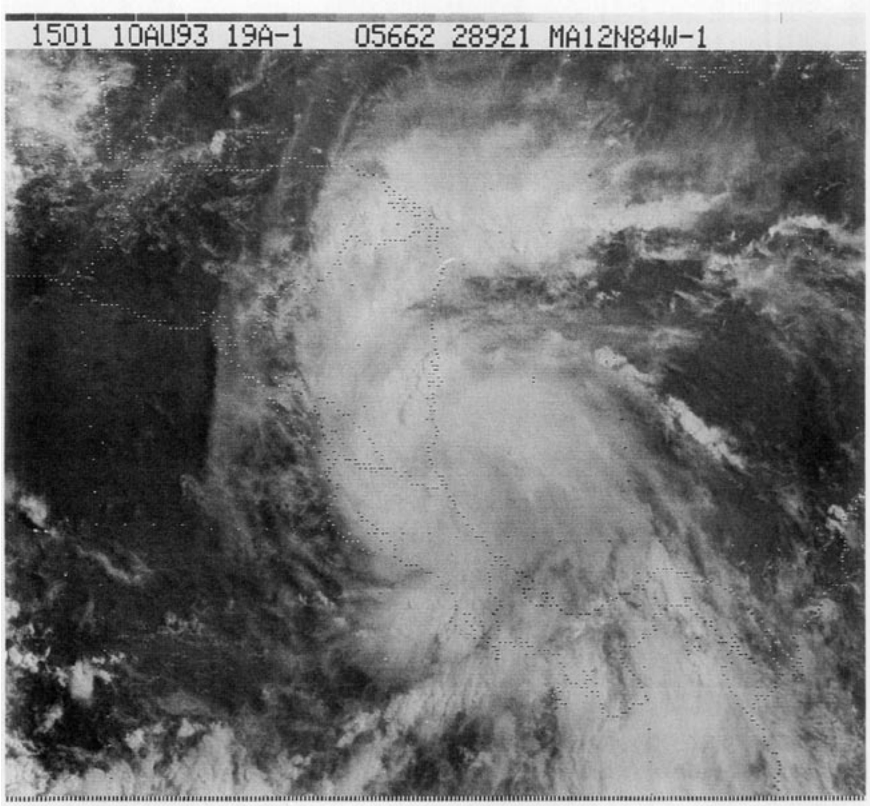

FIG. 4. *GOES-7* visible satellite image of rejuvenated Tropical Storm Bret at 1501 UTC 10 August 1993, just prior to landfall over southern Nicaragua.

less in Venezuela and Bret caused an estimated \$25 million worth of damage in that country. There was 1 death and 1 injury reported from Colombia. In Nicaragua, a total of 10 deaths were reported. Nine of these fatalities occurred offshore near Isla de Maiz when (according to ham radio reports) a Spanish vessel sank. There were also 35 000 persons reportedly "displaced" in Nicaragua due to Bret.

4) WARNINGS

The tropical storm warning provided about 24 h of lead time for the southern Windward Islands and the coast of Venezuela. There was only about 8 h of lead time for the coast of Nicaragua, when Bret rapidly redeveloped into a tropical storm over the southwest Caribbean Sea.

c. Tropical Storm Cindy, 14–17 August

1) SYNOPTIC HISTORY

Cindy formed from a tropical wave that moved off the northwest coast of Africa on 8 August. The cloud mass associated with this wave was easily tracked on satellite imagery as it moved west-northwestward between 8 and 10 m s^{-1} across the tropical Atlantic for the next several days. A U.S. Air Force Reserve aircraft investigated the disturbance on 13 August but found only a poorly organized surface circulation. On the next day, another aircraft found that the low-level circulation had become sufficiently better organized to indicate that a tropical depression had formed from this activity around 1200 UTC 14 August.

The tropical depression moved toward the west-northwest, steered by the low- to midlevel flow, and its forward motion slowed to between 5 and 8 m s^{-1}. The depression was upgraded to Tropical Storm Cindy at 1800 UTC 14 August while over the island of Martinique, based on 500-m flight-level winds of near 21 m s^{-1} from an aircraft and the observation of a central dense overcast in satellite imagery. Although the system appeared to have an efficient outflow pattern aloft when it was near the Lesser Antilles, this upper-level structure deteriorated and only a little additional strengthening occurred.

Cindy reached its estimated peak intensity of 21 m s^{-1} around 1200 UTC 16 August while centered about 140 km southeast of Santo Domingo, Dominican Republic. The lowest pressure reported by reconnaissance aircraft was 1007 mb at 1113 UTC. A relatively large area of 18–25 m s^{-1} winds was also reported from the aircraft at a flight level of 500 m near this time.

The tropical cyclone weakened when part of the circulation began interacting with the mountains of Hispaniola. Cindy was downgraded to a tropical depression at 2100 UTC 16 August when the poorly defined center moved over Barahona, Dominican Republic. The circulation rapidly became disorganized and the depression dissipated by 0000 UTC 17 August. However, the remnant cloudiness and showers spread over the southern Bahamas through 18 August.

2) METEOROLOGICAL STATISTICS

No sustained tropical storm force winds were reported from ships or island stations, but gusts to near 18 m s^{-1} were reported on Martinique. Gusts to 15 m s^{-1} were observed at St. Croix in the U.S. Virgin Islands and at Aquadilla, Puerto Rico.

The largest reported storm total rainfall was 305 mm at Precheur on the island of Martinique. Several reports of 102–254 mm of rain were received from various locations in the Dominican Republic and elsewhere over Martinique, while 76–102 mm of rain were reported over portions of Puerto Rico. It is likely that locally heavy rains occurred elsewhere over some of the Lesser Antilles and over Haiti.

3) CASUALTY AND DAMAGE STATISTICS

Flooding associated with Cindy caused two deaths in Martinique and two deaths in the Dominican Republic. Two persons were also reported missing in the Dominican Republic. Several hundred people were evacuated from flood-prone areas in Puerto Rico but no storm-related deaths were reported from this island.

Estimates of several million dollars in damage to private and public property including houses, roads, and seawalls have been reported from Martinique. There have been no other reports of significant damage received at the NHC related to Cindy.

4) WARNINGS

Tropical storm warnings were issued for the Lesser Antilles from Martinique northward and westward through the U.S. Virgin Islands, for Puerto Rico, and also for the Dominican Republic from Cabo Engano to Samana on the north coast and to Isla Beata on the south coast.

d. Tropical Storm Dennis, 23–28 August

On 21 August, a broad area of low pressure associated with a tropical wave moved off the African coast. This system was embedded within a large monsoon-type flow analyzed using satellite imagery and ship reports. Animation of visible *Meteosat-3* and *Meteosat-4* satellite images showed a distinct cyclonic rotation in the low clouds with increasing convection during the next day. The system became a tropical depression at about 1200 UTC 23 August.

The depression moved slowly westward and then west-northwestward, steered by a weak deep-layer mean flow. Based on the analysis of satellite images, the depression reached tropical storm status by 1200 UTC 24 August. Dennis intensified a little more, reaching its estimated peak intensity of 23 m s^{-1} and minimum pressure of 1000 mb at 0600 UTC 25 August, when convection was the strongest. Little change in intensity occurred during the next 24–30 h while the thunderstorm activity was gradually decreasing.

At that time, the axis of a rather strong middle to upper level trough became established near 50°W north of 20°N, causing Dennis to move north-northwestward. This track brought the storm over relatively cool waters and into an environment of increasing vertical shear, resulting in a separation of the low-level circulation center from the convection. Dennis weakened and was downgraded to a tropical depression at 1200 UTC 27 August. It dissipated 24 h later but the remnants meandered over the North Atlantic for a few more days.

e. Hurricane Emily, 22 August–6 September

Emily, the first hurricane of the 1993 Atlantic season, was the season's only major hurricane and also the longest lived. Its western eyewall passed over the North Carolina Outer Banks.

1) SYNOPTIC HISTORY

Emily moved off the west coast of Africa and over the Cape Verde Islands on 17 August as a tropical wave accompanied by a large cyclonic swirl of low- to mid-level clouds. The swirl moved westward at relatively high latitudes (15°–20°N) over the eastern Atlantic, where cool sea surface temperatures apparently limited the development of deep convection for the next several days. On 21 August, convection began to increase and become concentrated near the center of the cloud swirl, and by 22 August the system developed enough circulation and deep convection to be classified as a tropical depression, while located 1300 km to the east-northeast of Puerto Rico, at around 1800 UTC.

The depression moved toward the northwest at 5–8 m s^{-1} for two days. It then encountered a weak steering current, became quasi-stationary on 25 and 26 August, and began to intensify. Emily briefly reached hurricane intensity on 26 August, based on aerial reconnaissance observations and a report of sustained 33 m s^{-1} winds from a ship, the *OMI Missouri,* located about 90 km southeast of Emily's center at 1100 UTC. Shortly thereafter Emily's maximum winds dropped to just below hurricane force. A high pressure ridge built to the north and Emily, having regained hurricane intensity about 1600 km east of Florida, moved generally westward on

27 and 28 August while maintaining peak winds near 39 m s^{-1}.

Intensification began in earnest on 28 August, and Emily turned toward the northwest in response to the passage of a midlatitude short-wave trough to the north. The hurricane turned toward the west-northwest on 30 August as a short-wave ridge passed to the north. However, yet another trough in the westerlies neared Emily on 31 August and the hurricane began to turn northward. Intensification continued until late on 31 August when the hurricane was moving northward and the eyewall reached the Outer Banks of North Carolina (Fig. 5).

The hurricane reached its peak intensity late on 31 August as the center of the eye reached its point of closest approach to land, about 37 km east of Hatteras Island. Emily was large at this time with a 74-km inner diameter of the circular wall cloud surrounding the center of the hurricane. This is based on U.S. Air Force Reserve and National Oceanic and Atmospheric Administration (NOAA) reconnaissance as well as the Cape Hatteras radar. A portion of the western eyewall passed over Hatteras Island and the surrounding waters, with 1-min surface winds estimated between 33 and 51 m s^{-1}. This caused strong onshore winds on the Pamlico Sound side of Hatteras Island, and the accompanying storm surge coastal flooding was up to 3 m above normal tide levels. The Atlantic coast maximum surge levels were estimated to be only 0.3–0.6 m above normal.

For the record, Emily will be counted as a category 3 (major hurricane) landfall on the Saffir–Simpson hurricane scale (Simpson 1974) for Hyde and Dare Counties in North Carolina.

Emily was at the westernmost point of a recurvature around the western periphery of a large high pressure area when it affected the Outer Banks, and effects over land were minimal elsewhere. By 2 September, Emily had turned sharply toward the east in response to the most recent midlatitude trough and was weakening over colder North Atlantic water. It weakened to a tropical storm on 3 September as it moved southward and stalled. By 5 September, Emily was a tropical depression and moving east-northeastward. Emily became extratropical on 6 September far out in the Atlantic and quickly dissipated.

2) METEOROLOGICAL STATISTICS

The highest sustained wind measurement is 68 m s^{-1} from a U.S. Air Force Reserve plane at 1729 UTC 31 August, 30 km west of the center within a few hours of its point of closest approach to Hatteras Island.

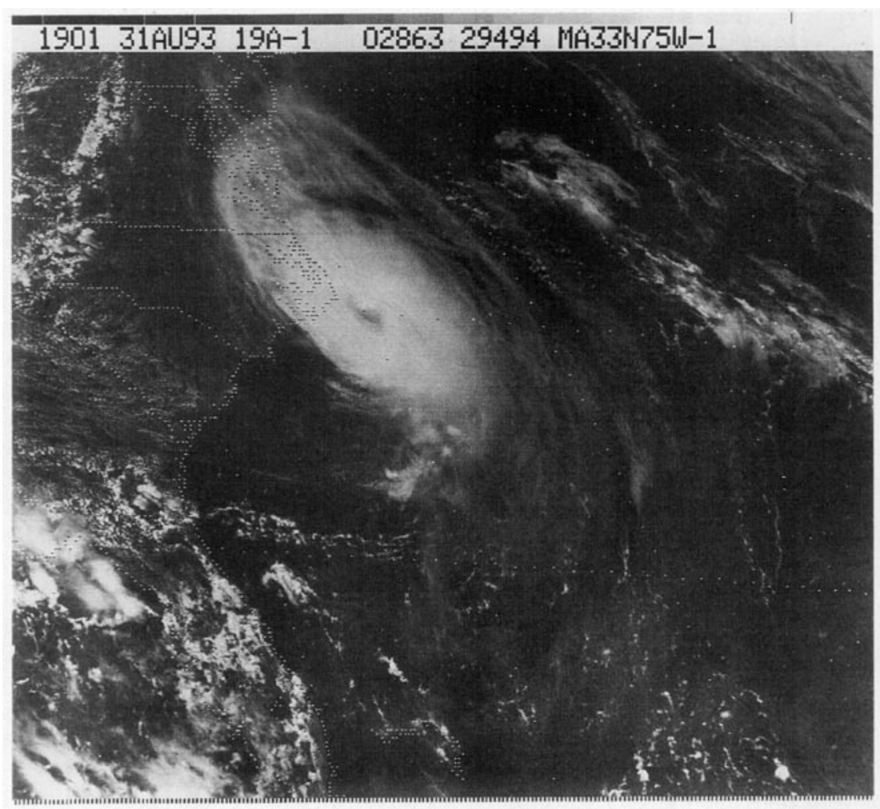

FIG. 5. *GOES-7* visible satellite image of Hurricane Emily at 1901 UTC 31 August 1993, near peak intensity just off the North Carolina Outer Banks.

TABLE 3. Hurricane Emily selected surface observations, 31 August–1 September 1993.

	Minimum sea level pressure		Maximum surface wind speed ($m\ s^{-1}$)				
Location	Pressure (mb)	Date/time (UTC)	1-min average	Peak gust	Date/time (UTC)[a]	Storm surge (m)[b]	Rain (storm total) (mm)
North Carolina							
Brigands Bay						2.6	
Buxton (HAT)	982.2	31/1925	27	44	31/2050	3.1	190.8
Buxton (citizen)			33	48	31/2215		
Buxton (R. Horodner)	976.5	31/2108					
Cedar Island ferry terminal			17	24	31/1830		
Duck pier	1000.5	01/0100	20	26	01/0100	0.5	
Diamond Shoals Light (elevation 46.6 m)	964.5	31/2100	44[c]	66	31/2225	2.6	
Frisco							
Gum Neck							25.4
Oregon Inlet			29	34	31/1846		
Wilmington (ILM)			8	11	31/1650		0
Virginia							
Chesapeake Bay Bridge			12	16	01/0600	0.4	
Norfolk	1008.8	01/0053	10	15	01/0151		0
Maryland							
Ocean City-mesonet	1009.1	01/0908	8	16	01/0908		71.1
Delaware							
Sussix County Airport			7	8	01/1517		0.3
Lewes						0.2	

[a] Time of 1-min wind speed unless only gust is given.
[b] Some of these values are height above MSL (above mean sea level).
[c] Two-minute-average wind speed.

The estimated maximum 1-min surface wind speed is 51 $m\ s^{-1}$ for 12 h beginning at 1800 UTC 31 August. This value turns out to be a reduction to 75% of 68 $m\ s^{-1}$, the 10-s aircraft wind at an altitude of 457 m. Table 3 lists significant surface observations. Diamond Shoals Light Tower is located 417 km southeast of Cape Hatteras, and its anemometer at 46.6-m elevation measured a 2-min wind speed of 44 $m\ s^{-1}$ at 2200 UTC and a peak 5-s gust of 66 $m\ s^{-1}$. They also measured a lowest pressure of 964.5 mb, only 4.5 mb higher than the aircraft-measured minimum pressure (960 mb) at 2349 UTC.

The National Weather Service Office in Buxton recorded a peak 1-min wind of 27 $m\ s^{-1}$ with a gust to 44 $m\ s^{-1}$, but the measurements were disrupted just before, it is believed, the strongest winds were occurred. A private citizen in Buxton recorded 33 $m\ s^{-1}$ with a gust to 48 $m\ s^{-1}$. Preliminary analysis at the NOAA Hurricane Research Division indicates 1-min surface winds speeds to as high as 49 $m\ s^{-1}$ over Pamlico Sound (S. Houston 1994, private communication). These strong onshore winds drove waters from Pamlico Sound onto Hatteras Island. A storm surge flood height of 3.1 m above sea level at Buxton is the highest reported value (Table 3).

The maximum rainfall recorded was 191 mm at Buxton, and very little was observed farther west. Ocean City, Maryland, reported 71 mm.

3) CASUALTY AND DAMAGE STATISTICS

A drowning in rough surf occurred along the Virginia coast on 31 August. Two other deaths due to similar circumstances were reported from Nags Head, North Carolina, on 1 September.

A preliminary damage estimate for North Carolina is \$35 million, mainly on Hatteras Island. There were 553 dwellings deemed uninhabitable. About 160 000 persons were evacuated from the barrier islands of North Carolina, 750 from the Virginia coast, 100 000 from the Maryland coast, 1000 from Delaware, and 20 000 from Fire Island, New York.

4) WARNINGS

Hurricane watches and warnings were issued from North Carolina through Delaware and a hurricane watch was also issued for the northern South Carolina coast. The watch was issued at 2100 UTC 29 August, or 47 h prior to the time of Emily's hitting the coast.

The warning was issued at 1800 UTC 30 August or 26 h in advance.

5) FORECASTS

Emily's recurvature near Cape Hatteras was quite well predicted by the NHC. This can be attributed to the generally good performance of the dynamical guidance models in forecasting the track of the hurricane up to its point of closest approach to the North Carolina Outer Banks. The Hurricane Research Division, using NOAA reconnaissance aircraft, conducted two synoptic-flow experiments when difficult evacuation decisions were being made. These provided meteorological observations, in particular midtropospheric winds, over a large, normally data-sparse, oceanic area in the path of the hurricane. These observations were used to initialize the National Meteorological Center's (NMC) global spectral numerical weather prediction model at 0000 UTC on 30 and 31 August. Since most of the NHC track guidance models use the NMC global model as input, the enhanced observational database likely had favorable impact on the other models as well. It should be noted that the NHC (and several of the models) track forecasts were considerably poorer after recurvature, when Emily was moving eastward.

f. Hurricane Floyd, 7–10 September

Floyd formed from a tropical wave that crossed the west coast of Africa on 28 August accompanied by relatively large height falls at low levels of the atmosphere. Inland surface reports in the vicinity of Dakar, and observations from several ships, indicate that the wave also contained a well-defined low-level cyclonic circulation surrounding a low pressure center of about 1009 mb on 28 and 29 August.

Satellite pictures indicate that the low moved steadily westward for about a week with deep convection periodically developing in its vicinity. Initial Dvorak technique satellite classifications began on 29 August, but by late 31 August the system became "too weak to classify" when thunderstorm activity nearly ceased. Deep convection redeveloped on 3 September about 925 km to the east of the Leeward Islands, but significant strengthening was limited by a southwesterly vertical wind shear.

The area of disturbed weather then gradually began to move northwestward and became better organized. On 6 September, a reconnaissance flight by the U.S. Air Force Reserves detected a broad area of surface pressures near 1011 mb centered within a weak low-level circulation about 275 km north of the Virgin Islands. On the following day, a reconnaissance mission detected a 1008-mb low within a small, low-level cir-

data are the basis for estimating that the system became a tropical depression during the morning of 7 September and that it strengthened to become Tropical Storm Floyd during the afternoon.

Floyd quickly became embedded in the fast air currents between a strong large-scale trough approaching the tropical cyclone from the northwest and a subtropical high to the east. The steering flow accelerated Floyd northward to 10 m s^{-1}, and the storm's center passed about 375 km to the west of Bermuda on 8 September. Strong southwesterly wind shear kept the system from strengthening and, in fact, the last reconnaissance flight in Floyd indicated that the central pressure had risen to 1012 mb by midday on 8 September. The system still appeared sheared on the day's final visible satellite pictures, with a low-level cloud center appearing poorly organized on the southwestern edge of the main area of convective clouds.

Floyd's structure changed considerably overnight and the storm intensified. By morning, the low-level circulation center was no longer exposed but was estimated to be near the center of the convective overcast. The storm was racing northeastward at about 18 m s^{-1} near the eastern end of the ribbon of warm Gulf Stream waters. Beginning near 1500 UTC, satellite imagery occasionally showed a recessed spot within the deep clouds near the estimated circulation center that could be interpreted as a partially formed eye. At 2000 UTC, the circulation center of Floyd passed about 75 km to the northwest of Canadian buoy 44141. The buoy reported a pressure of 998 mb, a sea surface temperature of 27.1°C, and a peak 2-min wind of 31 m s^{-1} during the hour ending at 2000 UTC. It is quite likely that a 1-min wind speed of at least 33 m s^{-1} occurred elsewhere within the southern part of the surface circulation, probably a little closer to the circulation center. Based on this analysis and the hint of an eye on satellite pictures, Floyd is estimated to have become a hurricane with 33 m s^{-1} maximum 1-min surface wind speeds at 1800 UTC 9 September.

Floyd's forward speed continued to increase late on 9 September and early on 10 September. The hurricane was moving at nearly 23 m s^{-1} when it began to lose its tropical characteristics over 19°C water. Deep convection diminished on 10 September and, as the day progressed, it became displaced farther to the northeast of the estimated low-level circulation center. Ship reports indicated an expanded wind field to the south. The system is estimated to have become an extratropical storm with 33 m s^{-1} winds at 1800 UTC 10 September.

Surface data indicate that the extratropical storm decelerated on an eastward heading over the following two days. The system began another deepening phase on 11 September, and its center neared the Brittany

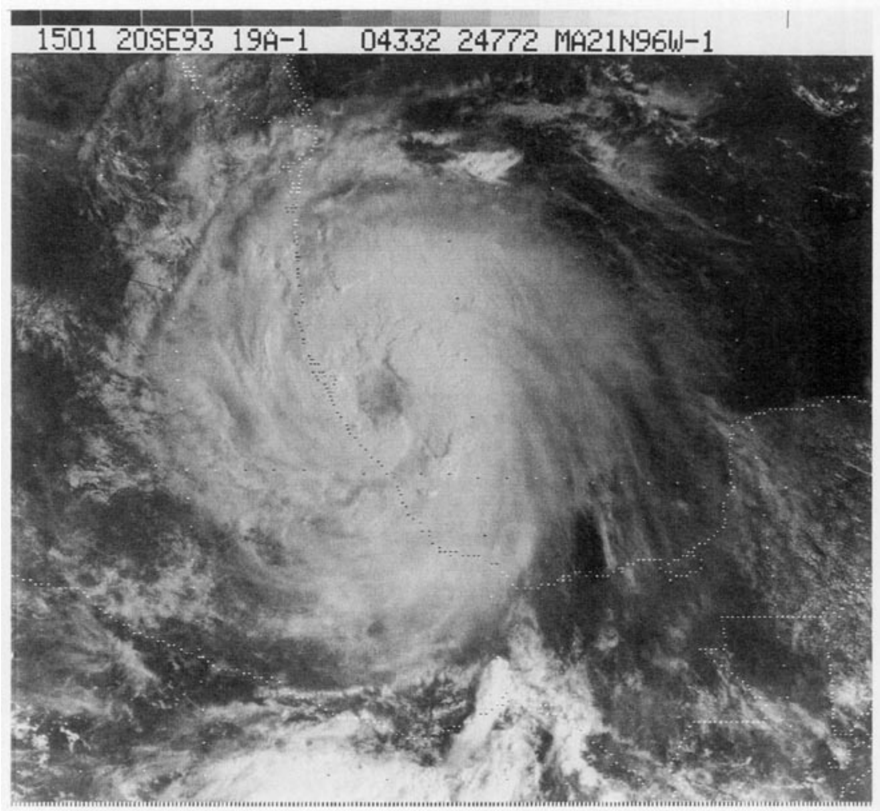

FIG. 6. *GOES-7* visible satellite image of Hurricane Gert nearing the coast of Mexico at 1501 UTC 20 September 1993.

g. *Hurricane Gert, 14–21 September*

1) SYNOPTIC HISTORY

A tropical wave passed off the west coast of Africa on 5 September well to the south of Dakar. The wave moved rapidly (near 10 m s^{-1}) westward across the tropical Atlantic for the next several days at rather low latitudes, causing some enhancement of convection in the intertropical convergence zone. The cloudiness associated with the wave became a little better organized when the system neared the Windward Islands, and a weak surface low associated with the wave passed over Trinidad on 11 September. Over the next couple of days, most of the system moved over the extreme northern part of South America. It emerged over the waters of the southwest Caribbean Sea late on 13 September. The upper-tropospheric environment over this region was favorable for development, and deep convection soon organized into curved bands. The tropical depression stage of Gert began at 1800 UTC 14 September, about 170 km off the north coast of Panama.

From the early stages of its existence, it was clear that Gert had a fairly large-sized circulation. This was evident not only from satellite imagery but also from rawinsonde data over the western Caribbean area. The depression strengthened to a tropical storm by 1200 UTC 15 September, as the associated cloud pattern continued to become better organized. Development was soon halted, when Gert's west-northwestward motion brought the center of the storm across the coast of Nicaragua in the vicinity of Bluefields around 1800 UTC 15 September. The center of Gert then began a nearly 2-day northwestward trek over the landmasses of Nicaragua and Honduras. The system weakened to a depression about 6 h after moving inland over Nicaragua but maintained enough of a surface circulation, over land, to retain depression status for the next 36 h. This was at least partly attributable to the large diameter of Gert's circulation, which was able to maintain some contact with the adjacent Caribbean and Pacific waters.

The depression emerged over the Gulf of Honduras around midday on 17 September and strengthened back to a tropical storm based on NHC satellite classifications and a report of westerly winds of 18 m s^{-1} from the ship *Chiquita Nederland.* Gert was moving north-northwestward at this time. The northwestward, and then north-northwestward, motion was apparently brought about by a mid- to upper-tropospheric cyclone over the eastern Gulf of Mexico. By 0000 UTC 18 September, Gert was moving inland again near Belize

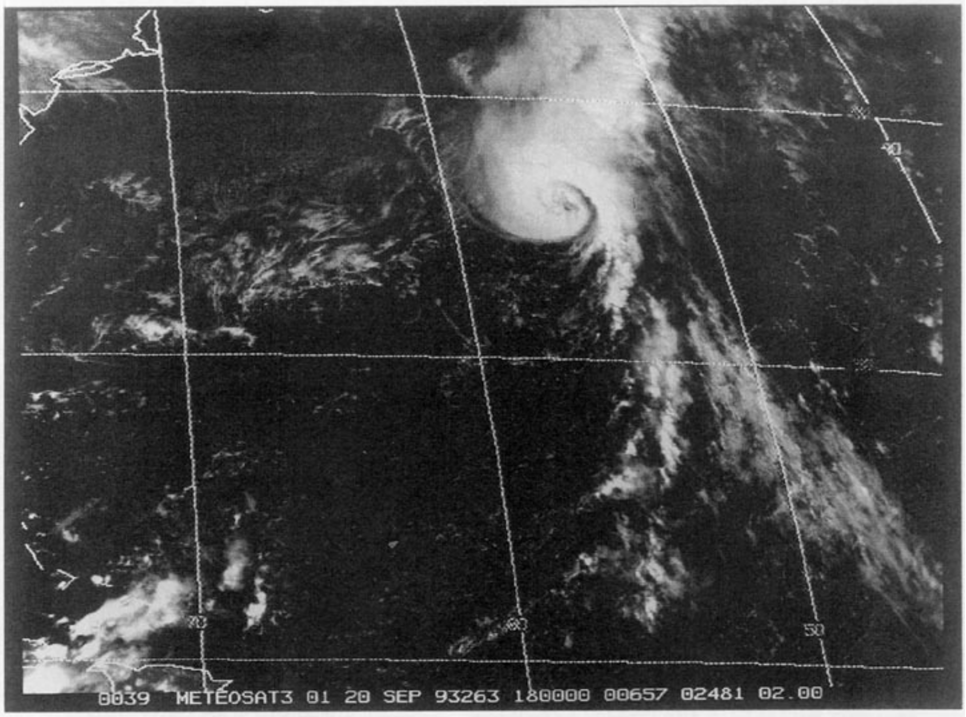

FIG. 7. *Meteosat-3* visible satellite image of Hurricane Harvey at 1800 UTC 20 September 1993, showing the appearance of an eye.

City, Belize, its time over water being of such short duration that the cyclone did not strengthen beyond minimal tropical storm intensity. A midtropospheric ridge over the northwestern Gulf of Mexico area forced Gert to turn back toward the west-northwest, and Gert, having weakened back to a depression, crossed the Yucatán Peninsula on 18 September. The center reemerged over water, this time over the Bay of Campeche, late on that day.

Now that the center was over relatively open waters, the opportunity for significant strengthening existed. Gert reintensified to a tropical storm by 0600 UTC 19 September, and 24 h later it became a hurricane. The forward motion slowed to less than 3 m s^{-1} around 0000 UTC 20 September, which allowed more time for the center to dwell over the warm waters of the southwest Gulf of Mexico. Consequently, Gert was able to strengthen to its maximum intensity of around 44 m s^{-1} just before making its third and final landfall. U.S. Air Force Reserve reconnaissance reports indicate that the central pressure fell to 970 mb. Figure 6 shows Gert on a visible satellite image a few hours prior to the final landfall. The eye of Gert, moving westward (or even a little south of west), crossed the coast of mainland Mexico just to the north of Tuxpan, Mexico, near 2100 UTC 20 September. A portion of the southern eyewall passed over Tuxpan around 2000 UTC. After moving inland, the center accelerated westward. Gert weakened

TABLE 4. Comparison of 1993 Atlantic official track forecast errors (rounded to the nearest kilometer) with 1983–92 10-yr average. A track forecast error is defined as the great-circle distance between a forecast position and a postanalysis best-track position for the same time. Cases include all subtropical storms, tropical storms, and hurricanes. Also shown is the range of the track forecast errors (km) for each forecast period.

	Forecast period (h)					
	0	12	24	36	48	72
1993 average	26	85	183	263	332	444
(Number of cases)	(118)	(97)	(81)	(71)	(60)	(41)
1983–92 average	30	96	185		372	570
1993 departure from 1983–92 average	−12%	−12%	−1%		−11%	−22%
1993 error range	0–113	0–369	11–789	33–1057	48–1063	78–1050

TABLE 5. Comparison of 10-yr average Atlantic official track forecast errors (rounded to the nearest km) for 1984–93 with 1974–83. A track forecast error is defined as the great-circle distance between a forecast position and a postanalysis best-track position for the same time. Cases include all subtropical storms, tropical storms, and hurricanes.

	Forecast period (h)			
	12	24	48	72
1974–83 mean	100	213	476	698
1984–93 mean	96	187	369	559
Departure of 1984–93 mean from 1974–83 mean	−4%	−12%	−23%	−20%

rapidly over the Sierra Madre Oriental of Mexico, and the cyclone was reduced to a tropical depression just after 0600 UTC 21 September. However, the fast-moving circulation was able to remain intact while crossing Mexico, and the center neared the Pacific coast of Mexico around 1800 UTC 21 September. It emerged over the eastern Pacific waters shortly thereafter, where it was reclassified as Tropical Depression Fourteen-E.

2) METEOROLOGICAL STATISTICS

No quantitative wind reports were received from Nicaragua. Chetumal, Mexico, reported winds to 20 m s^{-1}, presumably in gusts, around the time that Gert was making landfall near Belize (just to the south). Tuxpan reported winds to 46 m s^{-1}, Poza Rica (located about 45 km south of Tuxpan) reported winds to near 36 m s^{-1}, and Tampico reported winds to 26 m s^{-1}. It is not known if these were peak gusts or sustained values, but the former appears more likely.

Gert dumped copious amounts of rainfall over portions of Central America. Tegucigalpa, Honduras, reported 172 mm for the 24-h period ending 1200 UTC 18 September. A 24-h rainfall total of 188 mm was reported from Chetumal for the same period. However, the most massive rainfall amounts were recorded after Gert made its third landfall, where the broad circulation made contact with the eastern slopes of the Sierra Madre Oriental highlands of Mexico. Tanzabaca, Gallinas, and Tierra Blanca (all in the state of San Luis Potosi) reported rainfall amounts of 427, 326, and 323 mm, respectively, for the 24-h period ending near 1800 UTC 21 September. Tempoal and El Higo (state of Veracruz) measured 339 and 266 mm, respectively, for the same period. In contrast, Tuxpan (also in Veracruz), near the coast and in the eyewall, but mostly removed from orographic effects, reported 148 mm for the same 24-h period.

3) CASUALTY AND DAMAGE STATISTICS

The government of Mexico reported that Gert caused 42 deaths and 2 injuries in Mexico. Press reports indicate that there were 21 deaths in Honduras, 8 in Nicaragua, 4 in El Salvador, and 1 in Costa Rica. This makes a total of 76 deaths associated with Gert. Figures are sketchy on the total number of homeless due to Gert in Central America, but 100 000 appears to be a conservative estimate.

Damage totals are incomplete. The government of Mexico reported that 29 075 homes were damaged or destroyed and 145 000 acres of crops were destroyed, with a total damage estimate of about $156 million in Mexico. At least $10 million worth of damage reportedly occurred in Honduras, mainly in the northern part of the country. Reports of "considerable" damage to roads, by rains and mud slides, were received from Nicaragua.

4) WARNINGS

Tropical storm warnings were issued 15 h prior to Gert's landfall in Nicaragua, and 3 h before Gert's landfall in Belize. A hurricane watch was issued at 1500 UTC 19 September, about 30 h prior to landfall in mainland Mexico (near Tuxpan), and a hurricane warning was issued about 12 h before Gert's eye crossed the coast.

TABLE 6. Official maximum 1-min wind speed forecast errors (rounded to the nearest 0.1 m s^{-1}) for subtropical storms, tropical storms, and hurricanes in the Atlantic basin, 1993. Error = forecast − observed.

	Forecast period (h)					
	0	12	24	36	48	72
1993 mean	−0.9	+0.3	+0.8	+0.9	−0.1	−2.0
1993 mean absolute	2.2	3.3	5.1	6.2	7.4	9.5
(Number of cases)	(118)	(97)	(81)	(71)	(59)	(41)
Maximum error		−15	−18	−18	−21	−23
1983–92 mean		−0.8	−1.2		−2.3	−2.5
1983–92 mean absolute		4.0	5.9		8.4	10.6
1993 departure from 1983–92 mean absolute		−18%	−13%		−12%	−11%

h. Hurricane Harvey, 18–21 September

Harvey formed from a tropical wave that passed to the south of the Cape Verde Islands on 12 September. A cloud system center was identified in satellite imagery on this day, and Dvorak classifications were made intermittently over the next several days. Animation of satellite imagery indicated that the disturbance gradually became a little better organized as it interacted with an upper-level low on 18 September. A tropical depression formed from the disturbance, about 650 km south-southeast of Bermuda at 1800 UTC on 18 September based on a report of 19 m s^{-1} winds from a ship with call letters *ELFS*. The ship was located in a band of heavy convection that likely caused the wind speed in that area to be somewhat higher than was representative of the depression's interior circulation, centered about 240 km to the southwest of the ship. This interpretation is consistent with satellite intensity estimates, which indicated that the system's maximum sustained winds were 15 m s^{-1} or less at this time. The depression was moving generally to the north-northwest at 3–5 m s^{-1} but gradually turned more toward the northeast and accelerated in response to an eastward-moving short-wave trough approaching from the northwest.

Satellite imagery showed a low-level center exposed from disorganized deep convection on much of 18 and 19 September. However, by 1200 UTC 20 September, the circulation center moved under the deep convection and the system was upgraded to Tropical Storm Harvey. The cyclone briefly reached hurricane status at 1800 UTC when an eye appeared in satellite imagery (Fig. 7). By this time, Harvey was moving toward the northeast at about 15 m s^{-1}.

Harvey continued accelerating toward the northeast and soon passed over cooler waters. The system was downgraded to a tropical storm at 0000 UTC 21 September and quickly began to lose tropical characteristics. Harvey was declared extratropical at 1800 UTC 21 September, and the circulation was absorbed into a frontal band by 0000 UTC 22 September.

3. Verification

An ''official forecast'' of the center position and maximum 1-min wind speed is issued by the NHC for all tropical and subtropical cyclones in the North Atlantic Ocean, Caribbean Sea, and Gulf of Mexico. These forecasts are issued at 6-h intervals, for the periods of 12, 24, 36, 48, and 72 h. After each year's hurricane season, the forecasts are verified by comparing them to the ''best track'' postanalysis of all available data. Table 4 lists the average official forecast track errors for 1993. These errors range from 26 km for the 0-h forecast (i.e., the initial position error) to 444 km for the 72-h forecast. At all forecast times, the 1993 errors are less than the previous 10-yr (1983–92) average. Overall, there has been a gradual decline in the NHC track forecast errors over the past couple of decades. Table 5 shows the 1984–93 and the 1974–83 average official track forecast errors at 12, 24, 48, and 72 h. It can be seen from this table that the decrease in the most recent 10-yr averages versus those for the previous decade is most pronounced in the latter forecast time periods.

Table 6 lists the average official forecast wind speed errors for 1993. It can be seen that the forecasts had a positive bias (an overforecast) at 12–36 h and a negative bias (an underforecast) at 48 and 72 h. The mean absolute forecast wind speed errors for 1993 were somewhat smaller than those of the most recent 10-yr average.

Acknowledgments. Lixion A. Avila, Miles B. Lawrence, and Max Mayfield of the National Hurricane Center contributed to this report. We are grateful to Stanley B. Goldenberg and Robert E. Kohler of the NOAA Hurricane Research Division for providing the figure showing the vertical wind shear anomalies. We also thank Joan David for assisting in the preparation of the figures.

REFERENCES

Avila, L. A., and R. J. Pasch, 1995: Atlantic tropical systems of 1993. *Mon. Wea. Rev.,* **123,** 887–896.

Dvorak, V. F., 1984: Tropical cyclone intensity analysis using satellite data. NOAA Tech. Rep. NESDIS 11, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 47 pp.

Gray, W. M., 1967: The mutual variation of wind, shear and baroclinicity in the cumulus convective atmosphere of the hurricane. *Mon. Wea. Rev.,* **95,** 55–74.

Simpson, R. H., 1974: The hurricane disaster potential scale. *Weatherwise,* **27,** 169 and 186.